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SIMON
A Computer Program for Reliability and Statistical Analysis using Monte Carlo Simulation
Program Description and Manual

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Program Description and Manual

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Abstract SIMON is a program for calculation of reliability and statistical analysis. The program is of the Monte Carlo type, and it is designed with high flexibility, and has a large potential for application to complex problems like reliability analyses of very large systems and of systems, where complex modelling or knowledge of special details are required. Examples of application of the program, including input and output, for reliability and statistical analysis are presented.

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Contents

1 Introduction

The computer program SIMON is based on Monte Carlo simulation. The program is intended for reliability analysis of technical systems and for statistical analysis of mathematical functions by discrete value simulation of the independent variables in the functional expressions.

This report contains a description of the program and sample calculations for reliability as well as statistical analysis.

The program is written in FORTRAN 77, and is available in a VAX 4600 as well as a PC version.

Much effort was invested in obtaining a high flexibility of the program, in order to facilitate analysis of systems with complex design and/or operation and great freedom in the specification of the mathematical functions to be analysed and the corresponding independent variables.

SIMON is a further development of the MOCARE computer program (ref. 1). The largest improvements were implemented in the input part of the program, but SIMON has maintained many modelling facilities of MOCARE and a series of new features has been added.

2 Description

2.1 General

The SIMON program operates on two different principles - one when used for reliability analysis - and another when used for statistical calculations.

In section 2.2 and 2.3 below the operating principles of the program are described separately for each of these two kinds of analysis.

2.2 Operating Principles for Reliability Analysis

A reliability analysis concerns a study of the probability of a certain event, called the top event of the analysis.The top event of the analysis can, for instance, be the failure of a technical system, or it can be a certain sequence of events, each comprising failure/not-failure of a technical system or the occurrence of a certain scenario, comprising events and conditions.

The main principle of the operation of the program, when used for reliability analysis is based on the Monte Carlo technique. This implies, that the occurrence and not-occurrence of the top event is simulated a specified number of times. The resulting probability of occurrence of the top event is then calculated as the number of simulations, in which the top event occurred, divided by the total number of simulations.

The top event of the analysis is simulated by means of a top event model. The top event model - in general - is constructed by means of logical combinations of models of the causal events, which are the events, that will cause the top event. The causal event models - in turn - can in some cases also be expressed as combinations of models of causal events etc. The lowest level of the top event model contains event models, which are not expressed as combinations of models of other events. These event models are called *basic events*.

The basic events and the top event model in addition to the two different types of simulation, which can be used for reliability analysis, are described in detail in the following.

2.2.1 Basic Events

The basic events are two-state models, which are used for simulating the occurrence and not-occurrence of real events, like for instance failure to operate of an electric device or closure of a certain valve.

The basic events must be numbered, and the numbers can be selected between 1 and 4999 (inclusive). In order to save computer memory however, a successive internal index numbering is attributed to the basic events by the program, starting with 1 for the first basic event, specified by input data. The index numbering system is used for basic event model references and data throughout the program.

The occurrence of basic events is simulated in a subroutine called EVENT_SIM on the basis of the built-in random number generator of the computer. All basic events are in one of two states: occurred or not-occurred. Any basic event in the occurred state is indicated by the value 0 of the occurrence indicator array element IX(I), where I is the index number of the basic event. Correspondingly basic events in the not-occurred state are indicated by the value 1 of their occurrence indicator array elements.

The basic events can be of different types. Table 2.1 shows the 6 types, which can be specified in the present version of the program, including the corresponding input data. The first four types and data are identical to the corresponding calculation types and data in FAUNET, which is a program for system reliability and network analysis, based on an analytical approach (ref.2).

Basic event type 1

Basic event type 1 is a basic event type, which is characterised by a specified probability of occurrence per simulation trial.

Basic event type 2

Basic event type 2 is used for simulating events, characterised by exponential probability density functions both for the times between the occurrences and for the restoration times, which are the time periods, in which the events are in the occurred state.

Basic event type 3

Basic event type 3 is used for simulating events, characterised by exponential probability density functions for the times between the occurrences and constant restoration times.

Table 2.1. Basic event types.

Type no.	Designation	Data: Parameters	Data: Meaning	Remark
1	Constant failure probability per trial	NUMR ITY PARML(INDEX,1)	Basic event no. Type no. (=1) Probability per trial * 1.0 E6	
2	Exponential times to occurrence and exponential restoration times	NUMR ITY PARML(INDEX,1) PARML(INDEX,2)	Basic event no. Type no. (=2) Occurrence rate * 1.0E6 (h^{-1}) Restoration rate (h^{-1})	
3	Exponential times to occurrence and constant restoration times	NUMR ITY PARML(INDEX,1) PARML(INDEX,2)	Basic event no. Type no. (=3) Occurrence rate * 1.0E6 (h^{-1}) Restoration time (h)	
4	Exponential times to occurrence and constant restoration times	NUMR ITY PARML(INDEX,1) PARML(INDEX,2) PARML(INDEX,3)	Basic event no. Type no. (=4) Occurrence rate * 1.0E6 (h^{-1}) Restoration time (h) Test interval (h)	Restoration only at tests
5	Special distribution types for times to occurrence and restoration	NUMR ITY LTYP(INDEX) PARML(INDEX,1) PARML(INDEX,2) PARML(INDEX,3) RTYP(INDEX) PARMR(INDEX,1) PARMR(INDEX,2) PARMR(INDEX,3)	Basic event no. Type no. (=5) Occurrence distribution type no. Distribution par. 1 Distribution par. 2 Distribution par. 3 Restoration distribution type no. Distribution par. 1 Distribution par. 2 Distribution par. 3	
6	Data for events, occurring with a specified probability pr. occur. of spec. top event.	NUMR ITY TENO PARML(INDEX,1) RTYP(INDEX) PARMR(INDEX,1) PARMR(INDEX,2) PARMR(INDEX,3)	Basic event no. Type no. (=6) Top event no. Prob. per occurence of top event TENO Restoration distribution type no. Distribution par. 1 Distribution par. 2 Distribution par. 3	

Basic event type 4

Basic event type 4 is used for simulating events, characterised by exponential probability density functions for the times between the occurrences and constant restoration times, but the events simulated are not revealed by any means so that restoration will only take place at tests, carried out with intervals of the specified length of time.

Basic event type 5

Basic event model type 5 is used for simulating events, where the times between the occurrences and the restoration times can be specified by one of the distribution types below.

The parameters used in the distribution functions are called PARML and PARMR for the times between occurrence and restoration times respectively, see table 2.1 Below PARMx represents either PARML or PARMR.

<u>Distribution Type no.1</u>: Exponential p.d.f:

$$f(t) = \lambda \times e^{-\lambda(t-t_0)}$$

where:

λ = PARMx(INDEX,1)
t_0 = PARMx(INDEX,2)

<u>Distribution Type no.2</u>: Weibull p.d.f:

$$f(t) = K \times (t-t_0)^M \times e^{-\frac{K}{M+1}(t-t_0)^{M+1}}$$

where:

K = PARML(INDEX,1)
M = PARML(INDEX,2)
t_0 = PAPML(INDEX,3)

<u>Distribution Type no.3</u>: Normal p.d.f:

$$f(t) = \frac{1}{\sqrt{2\pi}} \times \frac{1}{s} \times e^{\frac{-(t-t_M)^2}{2s^2}}$$

where:

t_M = PARML(INDEX,1)
s = PARML(INDEX,2)

<u>Distribution Type no.4</u>: Log-normal p.d.f:

$$f(t) = \frac{1}{2\pi} \times \frac{1}{s} \times \frac{1}{(t-t_0)} \times e^{-\frac{(\ln(t-t_0)-t_M)^2}{2s^2}}$$

where:

t_M = PARML(INDEX,1)
s = PARML(INDEX,2)
t_0 = PARML(INDEX,3)

<u>Distribution Type no.5</u>: Constant times to occurrence:

$$f(t) = \delta(t-t_0)$$

where:

t_0 = PARML(INDEX,1)

<u>Distribution Type no.6</u>: Rectangular p.d.f:

$$f(t) = \begin{cases} 0 & \text{for } t<t_1 \\ \dfrac{1}{t_2-t_1} & \text{for } t_1 \le t \le t_2 \\ 0 & \text{for } t>t_2 \end{cases}$$

where:

t_1 = PARML(INDEX,1)
t_2 = PARML(INDEX,2)

<u>Distribution Type no. 7</u>: Beta p.d.f.:

$$f(t) = \frac{\Gamma(\gamma+\eta)}{\Gamma(\gamma)\,\Gamma(\eta)}\, t^{(\gamma-1)}\,(1-t)^{(\eta-1)}$$

where:

γ = PARML(INDEX,1)
η = PARML(INDEX,2)

<u>Distribution Type no. 8</u>: Gamma p.d.f.:

$$f(t) = \frac{\lambda^{\eta}}{\Gamma(\eta)} e^{-\lambda t}\, t^{(\eta-1)}$$

where:

λ = PARML(INDEX,1)
η = PARML(INDEX,2)

Basic event type 6

Basic event type 6 is used for simulating a special kind of events, which occur with a specified probability per occurrence of another event. The forementioned event could for instance be the failure of a ligther, and the latter, which is modelled by a top event with a specified number- an ignition attempt. The restoration times are specified the same way as for basic event model type 5.

2.2.2 The Top Event Model

The model for the top event of the analysis is a logical structure, in which the top event is expressed by means of logical combinations of models of other events, that will cause its occurrence. These events in turn can also be expanded into logical combinations of models of causal events etc.

All of the events in the structure, which are expressed by means of other causal- event models are called top events. All events, which are not expressed by means of other event models are called basic events.

The top events must be numbered between 5001 and 9999. Like for the basic events a successive index numbering is attributed to these events, starting with the maximum number of basic events, ANTBH,+1.

Like the basic events all top events are in either an occurred or a non-occurred state. For top event with index number I, the occurrence indicator array element IX(I) has the value 0, if the top event in the occurred state, and the value 1, if it is in the non-occurred state.

The logical model for the top event of the analysis is called a fault tree, because it is often used for modelling the failure of a technical system, but as mentioned above it can also be used for modelling of more complex event scenarios, for instance comprising both failure and not-failure of a series of systems.

The analyst is free to select any top event in the fault tree as the top event of the analysis - the event to be studied by means of the calculations.

The fault tree uses the following logical terms:

OR-GATE:	The output occurs, if at least one of the inputs occurs.
AND-GATE:	The output occurs, if all of the inputs occur.
NOR-GATE:	The output occurs, if at least one of the inputs does not occur.
NAND-GATE:	The output occurs, if all of the inputs do not occur.

An example of a simple fault tree is shown in fig. 2.1.

2.2.3 Reliability Analysis Simulation Type 1

Simulation type 1 for reliability anlysis is used for problems, which involve basic events, all of which are of types 1 and 6, see table 2.1.

This type of simulation follows route R1 at the flow diagram for the program, see fig. 2.2.

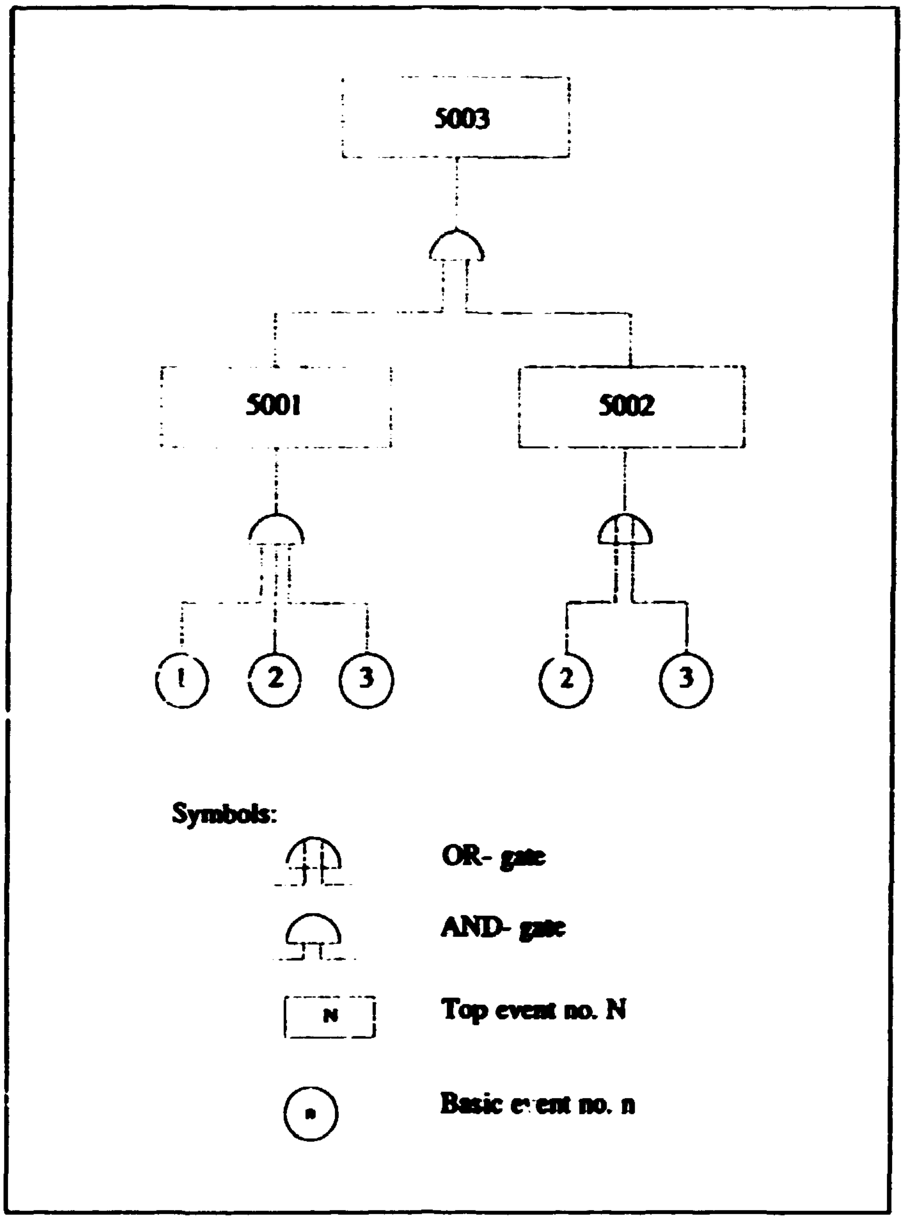


Figure 2.1. Fault tree example.

The specified number of Monte Carlo simulations, also called trials, are carried out.

In each of the Monte Carlo trials the occurrence and not-occurrence of all of the specified basic events are simulated only once as described in section 2.2.1 above concerning type 1. The occurrence or not-occurrence of the top event of the analysis is then determined on the basis of the specified fault tree as described in section 2.2.2 above. Possible basic events of type 6 included are generated as described in section 2.2.1.

After finishing the specified number of Monte Carlo trials, the number of trials, in which the top event of the analysis occurred, NSYFR, is counted and the resulting probability of occurrence of the top event of the analysis is calculated as NSYFR divided by the total number of Monte Carlo trials.

A variant can be specified for simulations of type 1 . The variant applies user defined analyses in each trial, based on other criteria, than fault trees, as well as user specified calculations to be performed after finishing the Monte Carlo trials.

The user specified analyses, to be performed in each trial, are made in the subroutines CALCn, where n is a calculation number= NCALC, specified by the input. The user specified calculations to be carried out after the trials have been finished, are made in the subroutines ENDCAn, where n equals NCALC. An example of a user specified calculation is presented in section 4.3.

2.2.4 Reliability Analysis Simulation Type 2

Simulation type 2 for reliability anlysis is used for problems, which involve basic events of other types than 1 and 6, see table 2.1.

This type of simulation follows route R2 at the flow diagram of the program, see fig. 2.2.

In each of the Monte Carlo trials all of the histories of the basic events included are generated over the specified period of observation 0-TMAX hours as illustrated in fig 2.3.

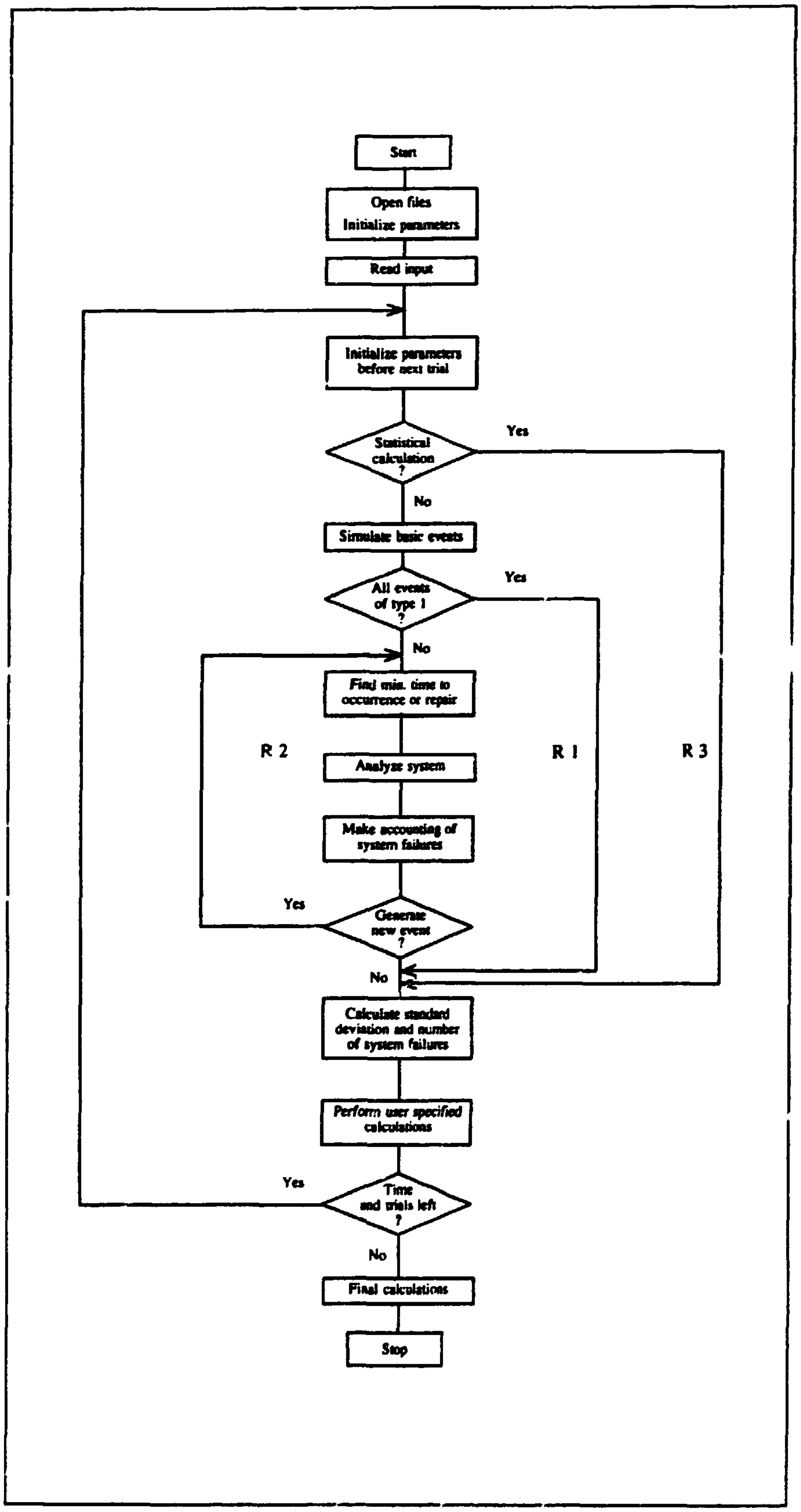
At any time during the period of observation, whenever one of the basic events changes from the occurred to the not-occurred state or vice versa the occurrence or not-occurrence of all of the top events is determined on the basis of the top event model as described in section 2.2.2. The model of the top event of the analysis, used in the example in fig. 2.3 is specified by means of the fault tree in fig. 2.1. At these moments of time the occurrence and not-occurrence of the type 6 events involved is determined in accordance with section 2.2.1.

In fig. 2.3 the periods, during which the basic events and the top events are in the occurred state, are indicated by hatched fields on the time axis.

After the specified number of Monte Carlo trials have been carried out, the characteristics listed below of the top event are calculated on the basis of the simulated periods, in which the model of the top event to be analysed, was in the occurred state. The terms mentioned in parentheses are those used in the case that the top event of the analysis is a failure of a technical system.

The probability of occurrence of the top event during the period 0-TMAX. (The system failure probability).
The probability of non-occurrence of the top event during the period 0-TMAX, (The system reliability).
The average fraction of the time, in which the top event occurred (The average unavailability of the system)
The average number of occurrences of the top event during the period 0-TMAX.
The average duration of the periods, in which the top event occurred.
The average time to the first occurrence of the top event.
The average CPU- time (s) per trial.

A variant can be specified for simulations of type 2 . The variant applies user defined analyses in each trial, based on other criteria than fault trees, whenever one of the basic events changes from the occurred to the not-occurred state or vice versa. In addition, user defined calculations to be performed after finishing the Monte Carlo trials can be specified.



Figu-e 2.2. Program flow diagram.

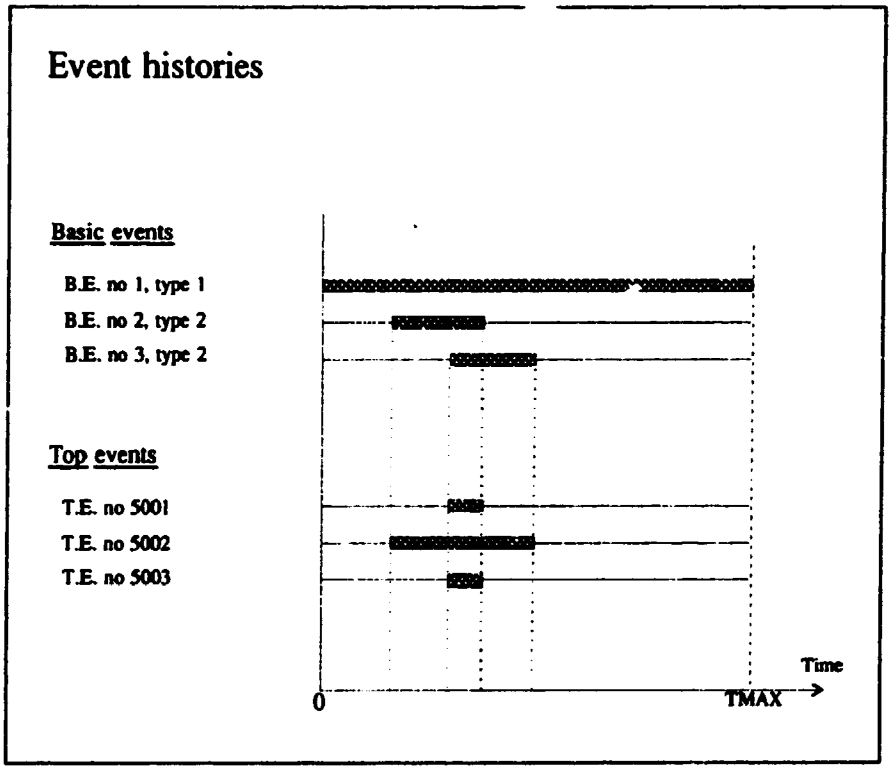


Figure 2.3. Principle for reliability analysis simulation type 2.

The user specified analyses to be performed in each trial, are programmed in the subroutines CALCn, where n is a calculation number= NCALC, specified by the input. The user specified calculations, to be carried out after the trials have been finished, are programmed in the subroutines ENDCAn, where n= NCALC.

2.3 Operating Principles for Statistical Analysis

The program can be used for statistical analysis of a function, defined by a mathematical expression, based on distribution functions for the independent variables of the function.

This type of simulation follows route R3 at the flow diagram of the program, shown in fig. 2.2.

In each Monte Carlo trial the values of the independent variables are sampled from the corresponding probability density distribution functions. Using these variable values, the value of the mathematical expression is calculated.

After the specified number of trials have been performed, a listing or a histogram of the sampled values of the mathematical expression can be obtained for presentation purposes or as the basis for further statistical analysis.

The data for the variables are specified the same way as the data for the basic events. The data type for these data is -1, and the parameters used are described in table 2.2.

Table 2.2. Data for variables in statistical analyses.

Type no.	Designation	Data	
		Parameters	**Meaning**
-1	Distribution types for variables, used in statistical calculations	NUMR ITY LTYP(NUMR) PARML(NUMR,1) PARML(NUMR,2) PARML(NUMR,3)	Variable no. Type no. (=-1) Occurrence distribution - type no. Distribution par. 1 Distribution par. 2 Distribution par. 3

The density distribution functions, which are included in the program at present, are the following: normal, log-normal, Gamma and Weibull distributions in addition to pointwise specified distribution functions of any kind, using rejection techniques (see for instance ref. 5 for details of the calculation techniques applied). The specification of distribution type is made by means of the parameter, ITY, the same way as for reliabilty data (see section 2.2) as described below. Of course other density distribution functions can also be incorporated, if required.

The generation of random values for statistical variables takes place in the user specified subroutines CALCn, using the function EPCST(NUMR).

The following probability density functions (p.d.f's) can be specified by means of the parameter, LTYP, for the variables, t, used in statistical calculations:

<u>LTYP= 10</u>: Constant probability, p (per sampling) :

where:

p = PARML(NUMR,1)

<u>LTYP= 14</u>: Log-normal p.d.f:

$$f(t)=\frac{1}{2\pi}\times\frac{1}{s}\times\frac{1}{(t-t_0)}\times e^{-\frac{(\ln(t-t_0)-t_M)^2}{2s^2}}$$

where:

t_M = PARML(NUMR,1)
s = PARML(NUMR,2)
t_0 = 0.0

<u>LTYP= 17</u>: Beta p.d.f.:

$$f(t)=\frac{\Gamma(\gamma+\eta)}{\Gamma(\gamma)\,\Gamma(\eta)}\,t^{(\gamma-1)}\,(1-t)^{(\eta-1)}$$

where:

γ = PARML(NUMR,1)
η = PARML(NUMR,2)

<u>LTYP= 18</u>: Gamma p.d.f.:

$$f(t)= \frac{\lambda^{\eta}}{\Gamma(\eta)} e^{-\lambda t} t^{(\eta-1)}$$

where:

λ = PARML(NUMR,1)
η = PARML(NUMR,2)

<u>LTYP= 20</u>: Pointwise specified p.d.f.:

The sampled values of the statistical variable, t, with the number N are generated in the function REJECT(N).

The p.d.f. of variable, t, is specified in the data file no. 15, the name of which is specified in the subroutine OPEN_FILE.

<u>LTYP= 21</u>: Normal p.d.f:

$$f(t)=\frac{1}{\sqrt{2\pi}} \times \frac{1}{s} \times e^{\frac{-(t-t_M)^2}{2s^2}}$$

where:

t_M = PARML(NUMR,1)
s = PARML(NUMR,2)

3 Input

The input for the program is specified by means of a main input file and, where relevant, a basic event data file and a fault tree data file.

The main input file may be replaced by interactive input via the keyboard for reliability calculations based on data files for a fault tree and basic events. By interactive input, the numerical data are of the free field format type; other input data must start in column 1.

The main input file is file no. 5. It specifies the calculations to be performed. It contains a series of data sections, each starting with a key word, specifying what the data section concerns, followed by numerical or alphanumerical data, where relevant.

The key words incorporated by file input, and the corresponding data specifications are listed in table 3.1.

All key words must be preceeded by a special character - for instance a $ sign for the purpose of structuring of the input. If data are to be given in connection with a key word, the data must be entered on the subsequent line(s) in accordance with table 3.1.

The sequence of the data sections can be chosen at pleasure, except the last one, which must always belong to the key word STOP. It is recommended, however, that for the convenience of the reader, the first data section is always the one with the key word TITLE.

The application of key words for input specifications makes the program very flexible, since the addition of new key words and input data is a simple matter.

Table 3.1. Input structuring key words for the main input file. (1/2)

Key word	Explanation	Data		Remark no.
		Parameters	Meaning	
CALCTY	Calculation type	NCALC	Type no.	1
CPUMAX	Max.cpu-time	CPUMAX	Max.cpu time (minutes)	
CUTS	Cut sets to be registered and printed out	KCU1,KCU2	Lower & upper limit for events included in the cut sets	
DATA	Name of the data file	FIL	File name	2
FAUNET	Top events specified by means of cut-or tie sets from the FAUNET program	NRSU,NFIL --- 0,BLANK	Top event no., name of cut set file	3
FTTREE	Specification of fault tree file	FILT	Name of fault tree data file	4
HISTOG	Specification of histogram data	BUNDI, TOPINT, IANTDL	Lower and upper boundary, number of intervals	
IMPSAM	Importance sampling required	ISTYP,FACIS	Type of IS, weighting factor	5
NOCUT	No cut sets are printed out.This key word can only be used together with key word CUTS	None		

Table 3.1. Input structuring key words for the main input file. (2/2)

Key word	Explanation	Data		Remark no.
		Parameter	Meaning	
NTRIMX	Number of simulation trials required	NTRIMX		
ORDNCS	Cut set listing to be ordered according to their total downtime	None		
PERIOD	Specification of simulation period	TMAX	Simulation period in h	
PLOFIL	Setting flag IPLOT=1 for storage of plot data on file 6	None		
RANDOM	Input of start number for random generator	NIX	Start number for random generator	
STAT	Statistical type of calculation required	None		
STOP	No more input data	None		This key word must always be used to indicate the end of the input data
TOPGAT	Top event to be analysed	NTOPGA	Top event number	
TITLE	Title of the problem	TITLE	Text on top of the output	

Remarks to table 3.1:

1. Re. CALCTY:

If non-standard calculations are required, this can be done by specifying a user defined subroutine, in which the desired calculations will be performed, after each simulation trial and/ or after the trials are finished. The figure NCALC is used as indicator of the subroutines to be applied. The user specified subroutine, corresponding to the number NCALC, is subroutine CALCan, where an= ABS(NCALC). If NCALC is negative, subroutine CALCan will be called every time any basic event changes from the not-occurred to the occurred state or vice versa. If NCALC is positive, the subroutine CALCan will be called only at the end of each trial. After all trials have been finished, user specified end calculations will be performed. This will be done by the user specified subroutine ENDCAan, where an has the same meaning as above.

2. Re. DATA

The data file with the name specified by the parameter, FIL, contains the data for the basic events or statistical variables for reliability or statistical analysis respectively.

The data file is read by means of the subroutine INPDAT. The file contains one line with numerical data and one descriptive text line for each of the data and must end with a blank line. The numerical data are descibed in table 2.1 and 2.2 respectively.

Basic event data files can be used for calculations not only by SIMON, but also by the FAUNET program. The FAUNET program, however, only uses basic event types 1-4.

3. Re. Cut set data file

The cut set data file, file no. 10, is produced by the FAUNET program and from this file the following parameters are read:

FTYPE(N),FNAME(N), where N= the cut set number, starting with 1
NFAUN(*), an array containing the decomposed cutsets

4. Re. Fault tree data file

The fault tree data file contains the specifications of the logic model of the system to be analysed. The file can also be used for calculations by means of the FAUNET program (ref.2). The fault tree data file contains the following data:

```
NAME
TEnumber
Gtype Gnumber Nentry EN(1) EN(2)...EN(Nentry)
*Gtext
---
---
$
```

where

NAME=	System name (Format A6, see example in section 4.1.2.2). NB! The first line of the basic event and the fault tree data files must contain the same system name.
TEnumber=	Optional: The numbers of the top events start with 5000, otherwise 2000 (Format I4)
Gtype=	+: OR gate x: AND gate -: NOT (NAND) gate N: NOT (NOR) gate
Gnumber=	Gate number (Format I4)
Gtext=	Optional:Explanatory gate text (Format A32)
Nentry=	Number of entries in the gate (Format I4)
EN(n)..=	Entry number n (Format I4)
$	File end

5. Re. Importance sampling

Importance sampling can be applied only for basic events of type 1, corresponding to a specified failure probability per simulation trial. Two different types of importance sampling can be applied. The following weighting takes place in the subroutine EVENT_SIM: If ISTYP= 1, all occurrence probabilities are multiplied with the weighting factor, FACIS. If ISTYP=2, all occurrence probabilities are muliplied by FACIS*PARML(NUMR,2). Correction for the weighting is made in the subroutine RESULT, where the final calculations take place.

4 Analysis Examples

4.1 Reliability Analysis based on a fault tree, simulation type 1 .

4.1.1. The Problem

A standard reliability analysis is required for a system where the failure logic is specified by means of a fault tree. The name of the fault tree data file is TEST.FLT. The top event to be analysed is event number 5005. Four basic events have been identified:

Basic event no.100:	Failure of fire detection equipment, type no.1, Occurrence rate=1.5E-3 h^{-1}
Basic event no.101:	Operator overlooks fire alarm, type no.1, Occurrence rate=2.0E-2 h^{-1}
Basic event no.102:	Failure of power supply, type no.1, Occurrence rate=2.5E-4 h^{-1}
Basic event no.103:	Failure of fire extinction unit, type no.1, Occurrence rate=3.6E-3 h^{-1}

The number of simulation trials required is estimated to: 10000.

4.1.2. The Input Data Files

4.1.2.1. The SIMON input file. (file no.5, name: TEST.SIM)

```
$TITLE
TEST CALC. ON F.T. TEST.FLT & DATA FILE TEST.EDA
$TOPGAT
 5005
$NTRIMX
 10000
$FTTREE
[HEK.EM]TEST.FLT
$DATA
[HEK.EM]TEST.EDA
$STOP
```

4.1.2.2 The fault tree data file (file name: TEST.FLT)

```
TEST
<5000
+5005   250065001
*Fire in factory
+5001   2 102 103
*Fail. of fire extinguishing
X5006   2 101 100
*EXTENSION
$ (indicates END OF FILE)
```

4.1.2.3 The basic event data file (file name: TEST.EDA)

```
TEST
 100,1, 1.5000E+03
*Fail. of fire det. equipment
*
 101,1, 2.0000E+04
*Operator overlooks fire alarm
*
 102,1, 2.5000E+02
*Failure of power supply
*
 103,1, 3.6000E+03
*Failure of fire ext equipment
*
(Blank line, indicates END OF FILE)
```

4.1.3. The Result File (File No. 6, Name: RES.DAT)

```
TEST CALC. ON F.T. TEST.FLT & DATA FILE TEST.EDA

TOTAL NUMBER OF TRIALS, ACTUALLY RUN        10000   NTRI

NO. OF TOP EVENT ANALYSED,  =                        5005


THE PROBABILITY OF OCCURRENCE OF THE
TOP EVENT DURING 0-TMAX (H)                 2.9000E-03
WITH THE STANDARD DEVIATION                 5.3774E-04


THE PROBABILITY OF NON-OCCURRENCE OF THE
TOP EVENT DURING 0-TMAX (H)                 9.9710E-01
WITH THE STANDARD DEVIATION                 5.3774E-04


AVERAGE CPU-TIME PER TRIAL                  2.1277E-02
NEXT STARTING NUMBER FOR
THE RANDOM GENERATOR                        -1238029115
```

4.2 Reliability Analysis, user specified failure conditions, simulation type 2.

4.2.1. The Problem

One of the tasks in Risø's project for the Danish State Railways (DSB) on "Reliability Analysis of the Great Belt Link" (ref.4) was to estimate the probability of failure of the connection between the control centres and more than three of the 31 cross tunnels connecting the two parallel main tunnels which form part of the link. A reliability model for the power supply and instumentation and control system was available; it had been constructed in connection with the qualitative analysis of the system. The corresponding fault tree and basic event data files were named STS012.FLT and STS012.EDA respectively.

4.2.2. The Input Data Files

4.2.2.1. The SIMON input file

```
$TITLE
STOREBAELT-FT STS012- SRO-FAILURE, COMM. W. 3 OR MORE CROSS
TUNNELS
$CPUMAX
 20.0
$PERIOD
 8760.0
$TOPGAT
 9014
$CALCTY
 -7
$FTTREE
[HEK.EM]STS012.FLT
$DATA
[HEK.EM]STS012.EDA
$STOP
```

The calculation type number ,-7, specified after key word CALCTY above, indicates that the user specified subroutine CALC7 will be called every time a basic event changes state, and the user specified subroutine ENDCA7 wil be called for performing final calculations after the specified number of trials have been completed.

4.2.2.2. The fault tree data file (file name STS012.FLT)

The fault tree data file is an extensive file (1311 lines), constructed like the file described in item 4.1.2.2 above.

4.2.2.3. The basic event data file (file name STS012.EDA)

The basic event data file is an extensive file (1900 lines), constructed like the file described in item 4.1.2.3 above.

4.2.3. The User Specified Parts of the Program

```
SUBROUTINE CALC7
*
* PERFORMS USER SPECIFIED CALCULATIONS FOR NCALC=-7
*

    INCLUDE 'SIMON.KOM'
    ISX=0

    DO 1 IY=1,31
    IF(IX(7100+IY*10+1).EQ.0)ISX=ISX+1
  1 CONTINUE

    IF(ISX.GE.3)TELLER=TELLER+1

    RETURN
    END

SUBROUTINE ENDCA7
*
* PERFORMS USER SPECIFIED FINAL CALCULATIONS
*
    INCLUDE 'SIMON.KOM'

    PRO=FLOAT(TELLER)/NTRI


    WRITE(6,'(A,E10.4)')' 'PROB. PER SIM.OF COMM. W. THREE OR
MORE TUNNELS FAILED'

    RETURN
    END
```

The array IX(n) above is ocurrence indicator. If IX(n)=0, event no. n is in the occurred state, if IX(n)=1, event no.n is in the not-occurred state. The index number, 7100+IY*10+1 equals the number used in the fault tree for the event 'Loss of communication with cross tunnel number IY'. The file SIMON.KOM, referred to in both subroutines, contains the COMMON fields used in SIMON as well as the declarations of variables.

4.2.4. The Result File (File No. 6, name: RES2.DAT)

```
    STOREBAELT- FT STS012- SRO- FAILURE. COMM. W. 3 OR MORE CROSS TUNNELS


    NO. OF TRIALS ACTUALLY RUN=                              6271

    NO. OF THE TOP EVENT ANALYSED  =                                  9014

    THE PROBABILITY OF OCCURRENCE OF THE TOP EVENT
DURING 0-TMAX(H)   2.3920E-03
    WITH THE STANDARD DEVIATION                              6.1666E-04

    THE PROBABILITY OF NON-OCCURRENCE OF
THE TOP EVENT DURING 0-TMAX(H)                               9.9761E-01
    WITH THE STANDARD DEVIATION                              6.1666E-04

    THE AVERAGE FRACTION OF TIME, IN WHICH THE
 TOP EVENT OCCURRED                                          0.3747E-06
    WITH THE STANDARD DEVIATION                              1.4235E-07

    AVERAGE NUMBER OF OCCURRENCES OF
THE TOP EVENT DURING 0-TMAX(H)                               2.3920E-03
    AVERAGE DURATION OF THE OCCURRENCES OF
THE TOP EVENT                                                1.3722E+00
    AVERAGE TIME TO THE FIRST OCCURRENCE OF
THE TOP EVENT (H)                                            4.1071E+03

    AVERAGE CPU-TIME PER TRIAL                               2.0801E+00
    NEXT STARTING NUMBER FOR THE RANDOM GENERATOR            -1497566907

    PROB. PER SIM.OF COMM. W. THREE OR
MORE TUNNELS FAILED=                                         0.2711E-02
```

In the above result file all data except the ones in the two last lines concern top event no. 9014, an event giving an approximate result, corresponding to communication through the four tunnel entrances.

4.3 Statistical Analysis

4.3.1. The Problem

Calculation of the probability of grounding of a ship is required. P.d.f's for the water depth (WATD, variable no. 1) and for the wave response of the vessel (GS, variable no. 2) are given as pointwise specified functions. The nominal draught of the vessel is V, and grounding occurs, if the resulting draught of the vessel, including the wave response exceeds the water depth. This occurs if (V+GS) > WATD.

4.3.2. The Input Data Files

4.3.2.1. The SIMON input file. (file no. 5, name: QAGR.DAT)

```
$TITLE
QATAR- GROUNDING PROBABILITY
$CPUMAX
 25.0
$STAT
$CALCTY
 6
$RANDOM
754339
$DATA
QAGR.EDA
$STOP
NOMINAL VESSEL DRAUGHT, V= (Comment)
11.54  (Parameter V, read in SUBROUTINE CALC6)
```

4.3.2.2. The basic event data file. (file name: QAGR.EDA)

```
QATAR
*
   1, -1, 20, 0.0, 0.0, 0.0
*WATERDEPTH
*
   2, -1, 20, 0.0, 0.0, 0.0
*FINAL RESPONSE-GS
*
```

4.3.2.3. The file with p.d.f's for variable 1 and 2.(file no 15, name: REJ_-QAT.DAT)

```
 1   (variable number)
 15  (number of point pairs, t,pdf(t))
 14.73 0.0   14.88 0.00628 15.08 0.0582 15.23 0.26    15.38 0.582
 15.58 0.94  15.73 1.02    15.93 0.90   16.13 0.66    16.33  0.48
 16.53 0.41  16.73 0.174   16.88 0.0764  17.03  0.0234 17.055 0.0
 2
 9
 0.0 12.3  0.288 10.3  0.576  7.0  0.864 4.7  1.152 4.6
 1.44 4.4  2.16 2.9    2.592 2.2   4.38 0.0
 0  (indicates END OF FILE)
```

4.3.3. The User Specified Parts of the Program

```
SUBROUTINE CALC6
*
*  PERFORMS SPECIFIED NON-STANDARD CALCULATIONS
FOR NCALC=6
    INCLUDE 'SIMON.KOM'
    ISX=0
    N6EX=N6EX+1
    IF(N6EX.EQ.1)THEN
    WRITE(6,'(A)')' V= '
    READ(5,*)
    READ(5,*)V
    END IF

    WATD=EPCST(1)
    GS=EPCST(2)

    IF((V+GS).GT.WATD)TELLER=TELLER+1

    RETURN
    END


    SUBROUTINE ENDCA6
    INCLUDE 'SIMON.KOM'
*

*   PERFORMS FINAL CALCULATION OF THE GROUNDING
    PROBABILITY

    WRITE(6,*)' TELLER= ',TELLER

    PRO=FLOAT(TELLER)/NTRI

    WRITE(6,'(A,2X,F10.8)')' GROUNDING PROBABILITY= ',PRO

    RETURN
    END
```

4.3.4. The Result File (File No. 6, Name: RES3.DAT)

```
TELLER=        237
V=   11.54

NO. OF TRIALS RUN=        66910

GROUNDING PROBABILITY=   0.00354207
```

5 Acknowledgement

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6 References

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SIMON

A Computer Program for Reliability and Statistical Analysis using Monte Carlo Simulation

Program Description and Manual

Hans Erik Kongsø and Kurt Lauridsen

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Abstract (Max. 2000 characters)

SIMON is a program for calculation of reliability and statistical analysis. The program is of the Monte Carlo type, and it is designed with high flexibility, and has a large potential for application to complex problems like reliability analyses of very large systems and of systems, where complex modelling or knowledge of special details are required. Examples of application of the program, including input and output, for reliability and statistical analysis are presented.

Descriptors INIS/EDB

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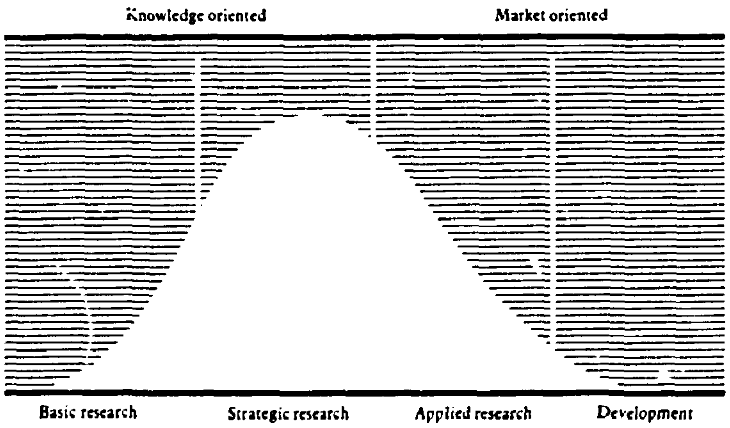

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